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Written Testimony of Steve Oldham
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Before the Senate Environment and Public Works Committee
February 27, 2019

Introduction and Executive Summary

Mr. Chairman, Senator Carper, and the other members of the Committee, thank you for the opportunity to participate in this hearing and to submit written testimony. My name is Steve Oldham and I'm the CEO of Carbon Engineering, where we have developed a direct air capture technology that removes carbon dioxide from the atmosphere, creating a valuable product that can be used or stored.

Figure 1: Commercial-Scale Direct Air Capture (DAC) Unit.

To understand where our technology fits, imagine that the atmosphere is simply a bathtub that holds all gases including carbon dioxide (CO_2). The world is measuring a higher and higher fill level on the amount of CO_2 in the bathtub, so in our attempts to decarbonize, we are trying to turn down the CO_2 tap.

But the other way to deal with too much CO_2 in the atmospheric bathtub is to open up the drain. While there are natural carbon removal techniques like afforestation, never before have we been able to open up the bathtub drain at large scale through technical means.

Our technology, which is demonstrated and commercially viable, enables CO_2 to be pulled out of the atmosphere at large scale and then permanently sequestered underground or used to manufacture transportation fuels and other industrial products. Our technology is similar to carbon capture on industrial flue stacks, but distinct and complementary in that we capture directly from the more dilute CO_2 in the atmospheric air.

Within my written testimony I will cover:

1. Carbon Engineering's successful efforts over the last ten years to solve the DAC technical challenges and capture atmospheric carbon for as little as $100 per ton.
2. Our new partnerships including those with world-class industrial companies like Occidental Petroleum, Chevron, and BHP.
3. Our commercialization plans and the potential for significant economic development in the US through production of CO_2 and liquid transportation fuels.
4. The positive impact of the USE IT Act.

Background on Carbon Engineering

Since our founding in 2009, we have designed and engineered our technology to be deployed at large industrial scales. Our commercial direct air capture plants are designed to capture 1,000,000 metric tons of carbon dioxide per year. At that scale, one facility is processing a quantity of CO_2 equivalent to the emissions from 250,000 average cars. We designed our technology for these large scales because these are the capacities at which oilfield operations, geological injection of CO_2, and large fuel refineries operate. As an example, the energy industry utilizes 50 million tons (megatons) of CO_2 each year to inject underground to help produce oil in the Permian Basin through a technique called enhanced oil recovery. In part due to positive measures such as 45Q, some estimates show that this amount could triple in coming years to a demand of 150 megatons of CO_2. Existing supplies of CO_2 – primarily from geologic sources -- are not enough. We are ready to meet that demand with atmospheric CO_2. Since our only feedstocks are air, water, and energy, our plants can be located adjacent to existing pipelines and oilfields to deliver CO_2 at point of demand, and our costings show that this can be economical today.

What Carbon Engineering has achieved over more than a decade of research and development – the ability to remove carbon dioxide from the atmosphere for as little as $100 per ton – is significant. Carbon Engineering's technology represents a tremendous economic opportunity for the United States to lead on innovation around CO_2 capture and utilization. Our CO_2 capture plants will help established fossil energy companies to decarbonize their portfolios, while enhancing domestic energy security and creating entirely new domestic manufacturing industries that will utilize captured CO_2 for the production of fuels, chemicals and industrial products. Carbon Engineering's technology provides a market-based solution for simultaneously meeting the demands of existing industries and decarbonizing the economy.

I assumed the leadership of Carbon Engineering a little over a year ago, after building and running a number of businesses in the satellite and high-tech sectors, to help commercialize what I recognized then, and continue to believe now, to be an important game-changing technology. Carbon Engineering had been founded in 2009 by Professor David Keith, who is now at the Harvard University School for Engineering and Applied Sciences and the Kennedy School for Government. He raised seed capital from a small group of investors, including Bill Gates, to create and commercialize this important technology.

David and his investors saw the potential in direct air capture and founded the company with the mission to develop and engineer a system that could be brought to market affordably and at industrial scale, and which could play a mainstream role in cutting emissions and producing clean energy. Since 2009, the team at Carbon Engineering – now over 50 individuals -- has been able to do just that. Our technology is proven, the leading commercial markets are ready, and we've formed core strategic partnerships with some of the world's largest energy companies. Our mission now is to be the preferred solution for the capture and utilization of atmospheric CO_2, by providing technology that is economic, accessible, and effective.

And that's happening -- we're getting major buy-in and validation from private industry. We recently received investments from Occidental Petroleum, Chevron and BHP (Formerly BHP Billiton), each of whom see our technology as a strategic asset in delivering affordable – and increasingly clean – energy to consumers. This strategic interest will be key as we continue to develop project opportunities in locations such as Texas, Wyoming, Oklahoma, the Dakotas, New Mexico, Colorado, Nevada, and California – where

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carbon dioxide is used in oilfield operations, where renewable energy is available, and where markets are demanding increasing quantities of domestic, low-carbon fuels.

Direct Air Capture Technology Description

"Direct air capture" is the term used to describe the process of capturing carbon dioxide directly out of atmospheric air with an engineered, mechanical system. DAC, as it is known, pulls in atmospheric air and through various chemical reactions, extracts the carbon dioxide within it, and returns the rest of the air to the environment. This is what plants and trees do every day as they photo-synthesize, except DAC technology does it much, much faster, and delivers the carbon dioxide in a pure, compressed form which can then be stored underground or used to manufacture products like clean transportation fuels. DAC is a similar, and complementary, technology to "carbon capture and storage" which removes carbon dioxide from industrial flue gas instead of the atmosphere.

Over our ten years of work at Carbon Engineering, we have developed and now demonstrated a direct air capture technology that is cost effective, ready for market, and which can be deployed at large industrial scale. We've done this by borrowing already commercial and widely used equipment and modules from other industries, and then innovating and integrating around them to create a fully-integrated DAC system.

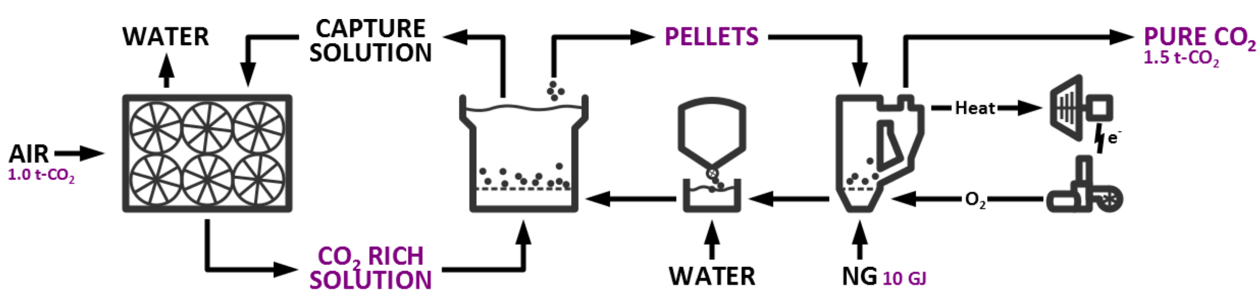

Figure 2: Schematic of CE's DAC Technology. Inputs are air, water, and energy. Output is pure, compressed, CO_2 ready for injection or use.

Fundamentally, our technology has four main steps (See Figure 2):

1. Our "air contactor" – built with design philosophy from the industrial cooling industry – pulls air in and reacts it with an alkaline liquid solution known as potassium hydroxide. It is non-toxic, non-volatile, and reacts with atmospheric carbon dioxide to form a salt known as a carbonate. As air is passed through our device, carbon dioxide is removed, until once discharged from the outlet back into the environment, the air has only one quarter of its original CO_2; the rest having been absorbed into our liquid. This means air goes in with 400 parts per million (ppm) of CO_2, and comes out with only 100 ppm CO_2, and then the discharged air quickly mixes with the rest of the atmosphere.
2. A second step takes the carbon dioxide we have absorbed and reacted to form carbonate and causes this to precipitate out of solution in solid form. This module uses technology from the wastewater treatment industry. This is very similar to a glass of salt water that evaporates, and

leaves behind a precipitated ring of salt. In our case, we don't evaporate, we use a chemical reaction to cause precipitation. What we have after this step is a solid carbonate, containing the CO_2 we have captured from air, that we can further process.

3. In the last major step of our process, we heat this carbon dioxide-carrying carbonate to high temperature, which causes it to release pure CO_2. We do this in a closed vessel – adapted from mineral and ore processing – so we can capture and compress the CO_2 that is released and deliver it for use or storage.
4. Finally, to complete our process, we take the solids that are left behind from the high-temperature CO_2 release, and we mix them with water to return to our system. This mixture actually re-creates the original capture chemical used in the air contactor to absorb CO_2, and the cycle begins again.

These four steps, all taken together, mean that we have a "closed loop" chemical process that captures and purifies atmospheric carbon dioxide. Closed loop means that we don't require a constant supply of chemicals to operate; rather, we simply need water and energy. The energy for our system can come in two main forms. We either operate with clean, low-carbon electricity, or we can operate by using natural gas as our energy source. In this latter case, we are able to take advantage of cheap and abundant natural gas to power our system, and we capture all of the carbon dioxide created by the gas, so that both the CO_2 from the air and from the natural gas are purified and compressed for further use. This is important because it keeps us from releasing CO_2 and counter-acting the CO_2 that we have absorbed.

Uses of Direct Air Capture

We have developed our Direct Air Capture technology with a few key uses in mind, which now form the project opportunities that we are developing along with our strategic investors. First, our technology allows atmospheric carbon dioxide to be collected and purified at any location. Our system works just as well in West Texas as it would near a busy highway or big city and we are cultivating opportunities to capture and deliver carbon dioxide to where it is demanded for both geological sequestration and enhanced oil recovery. Enhanced oil recovery has been in practice since the 1970's, and American energy companies inject over fifty million tons of CO_2 per year and need more. Current supplies are mostly CO_2 produced from geologic wells, but these are limited, and direct air capture offers the opportunity to produce CO_2 at point of demand and also to leave atmospheric CO_2 underground permanently during oil production. One of our largest investors, Occidental Petroleum, sees significant value in applying our technology to their oilfield operations in the Texas Permian Basin where they use it to manage reservoir production, and can manage their reservoir engineering to permanently store the carbon dioxide underground. We see additional value in deploying our technology in locations that have injectable geology but limited carbon dioxide pipeline capacity, such as areas of Wyoming, the Dakotas, the Gulf coast, and California.

Another commercial opportunity to utilize our CO_2 is to supply atmospheric carbon dioxide that can create valuable industrial products. Some are starting to call this broad concept "electrons to molecules". We have in fact developed a process that we call Air to Fuels™, which pairs our air capture system with renewable hydrogen, in order to provide both carbon dioxide and hydrogen as feedstocks for direct refining of liquid fuels (See Figure 3). Our Air to Fuels™ process allows us to harness low-carbon or renewable electricity, such as that produced by wind turbines or solar panels – which is often intermittent – and to split water to make hydrogen. Instead of trying to sell the renewable electricity or the hydrogen, we instead combine the hydrogen with captured atmospheric carbon dioxide and directly refine it into a liquid fuel such as diesel or Jet-A. This has several benefits, including increasing the demand for renewable energy, as well as producing a hydrocarbon drop-in fuel that is compatible with existing refineries and engines. As with the case of using atmospheric CO_2 for underground injection, we are now seeing significant interest in our Air to Fuels™ technology to deliver the increasing volumes of low carbon fuels demanded in leading markets like California, Oregon, British Columbia, and Europe.

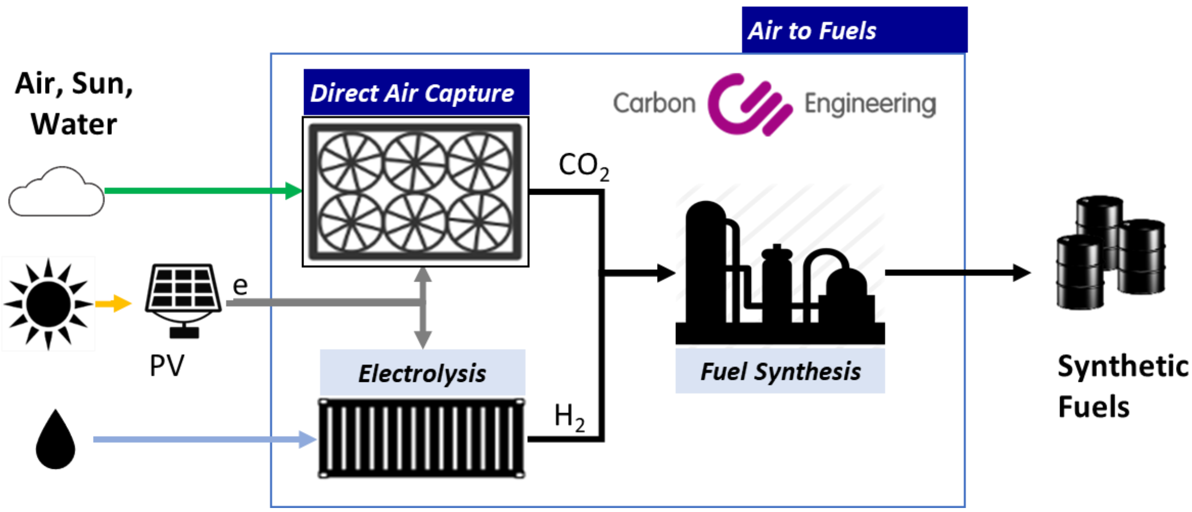

Figure 3: Schematic of CE's Air to Fuels™ Technology. Air to Fuels builds on direct air capture, and clean electricity, to directly produce liquid fuels like gasoline, diesel, and jet.

As an additional note, direct air capture, when coupled with geological sequestration, allows us to achieve what is known as "carbon dioxide removal" or "negative emissions." As companies and nations tackle commitments to reduce environmental footprints and cut emissions, many are starting to recognize that in certain sectors, cutting emissions at their source is too costly or challenging to be practical. In certain industrial or agricultural sectors, emissions-reducing fixes are difficult to imagine. So rather than stopping or limiting activity in such sectors, direct air capture with permanent sequestration could be used to capture and store an equivalent quantity of emissions, thus offsetting the impact of the facility or practice in question. Further, in far future scenarios, if and when carbon emissions have largely been eliminated, negative emissions provided by direct air capture can allow us to achieve "global net negative" scenarios and to begin reducing the concentration of CO_2 in the atmosphere.

Status and Trajectory

To date we have been almost entirely supported by private capital, coupled with early-stage R&D support from government sources. Our early private equity financing rounds allowed us to develop, engineer, and demonstrate the technology. We secured funding – largely from competitive, performance-based government funding solicitations – to augment our private capital, and we have been proud recipients of a grant from the US Department of Energy to help us operate our direct air capture pilot facility and continue to advance the technology. This early work allowed us to demonstrate both our Direct Air Capture and our Air to Fuels™ technologies at pilot plant scale. Our direct air capture pilot was commissioned in 2015 and can capture a ton of carbon dioxide from the atmosphere each day, and our full air to fuels pilot made first fuels from atmospheric carbon in late 2017 (See Figure 4).

Figure 4: CE's DAC Pilot Facility. Commissioned 2015, capture capacity 1 ton- CO_2/day.

Having demonstrated these technologies, we are now poised to close a $60 million USD financing round that will see us continue our disciplined scale up strategy and will allow us to start work on first commercial projects. We have secured funding from Occidental Petroleum, BHP, and Chevron as investors in this round, and we anticipate announcing additional major investors in March 2019.

This funding round will enable us to deploy a larger, fully-integrated system - roughly 5-10-times greater capacity than what has been done to date. We'll deploy this equipment at our existing facility, and its engineering, fabrication, commission, and operation life-cycle will take us roughly two years. The data and experience from these scale-up efforts will be used to validate our commercial scale designs, and to adhere to best-practice disciplined engineering scale up. Overall, this continues the hardware-driven approach we've used as a company since day one, and allows our engineers to deploy early commercial facilities with high confidence and low risk.

At the same time, we are already starting to develop our first commercial facilities, with several of our leading candidate sites being here in the United States. We're working with our lead investors, and other potential partners, to develop first commercial facilities. There are a number of candidate locations, but for example, one project would see us deploy a direct air capture facility capable of delivering 100,000-500,000 metric tons of CO_2, via an existing pipeline for use in oilfield operations in Texas. The facility would cost in the range of $300-600M USD, would create several hundred construction jobs and over a hundred permanent jobs, and would pay back a positive internal rate of return (IRR) to investors (even for this first project) from the value generated by CO_2 delivery and by generation of California Low Carbon Fuel Standard credits and 45Q tax credits for permanent capture and storage of CO_2.

Figure 5: Depiction of a Commercial CE Air to Fuels™ Plant.

We are also pursuing opportunities to acquire electricity from renewable power developers – which at some locations can be difficult to sell due to its intermittency – to drive full Air to Fuels™ facilities (see Figure 5). Again, we see leading candidate sites in Texas, but potential for deployment in Colorado, New

Mexico, Nevada, and other locations, as well. Such an early facility would likely produce 500 barrels per day of a product known as “Fischer-Tropsch Synthetic Crude” which could be processed in existing refineries into the usual slate of gasoline, diesel, and jet fuels (See Figure 6).

Figure 6: Fuel production at CE’s facility.

Five hundred barrels per day is small by refining standards, but in both the stand-alone direct air capture, and the Air to Fuels configurations, our expectation is that energy industry and finance sector players need to see these early plants executed well before they’ll allow us to finance bigger installations. These early commercial projects will be challenging. We have demonstrated technology, and market demand, but first projects often require extra help, and we see the mutual benefit of an active Government role here, on which we would welcome further discussion.

Once through early projects, we anticipate deploying growing numbers of both stand-alone direct air capture and air to fuels facilities at increasingly larger scales. With the full economics of scale shown by our engineering work to-date, we anticipate that these facilities are financeable from competitive capital markets, and can be a self-sustaining, self-perpetuating industry based on the value of CO_2 and fuels produced, and credits generated under California’s Low Carbon Fuel Standard. Eventually, with improved optimization and economics, we see the same technologies having significant export potential, and being applied in multiple regions of the world.

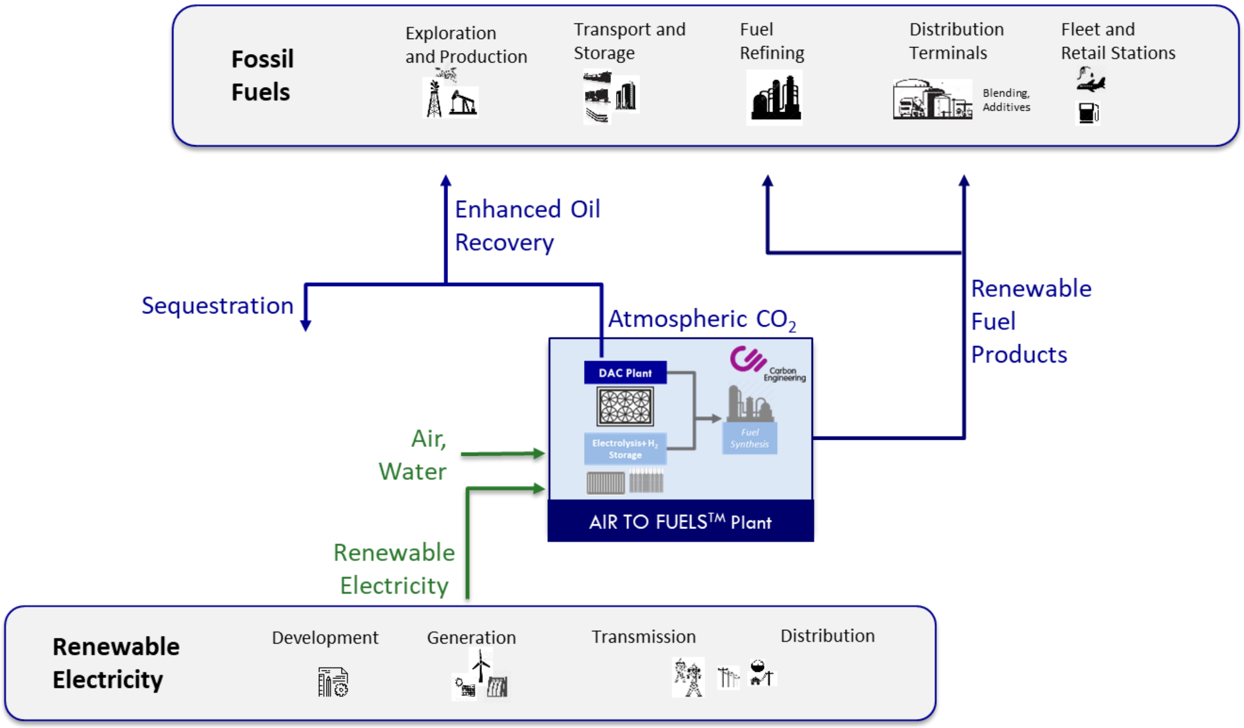

Figure 7: Industry impacts: CE's DAC and Air to Fuels™ technologies play a key role in "electrons to molecules".

Supportive Public Policies

Mr. Chairman, we appreciate your role – and the role of Senator Whitehouse and others – in developing and reintroducing the USE IT Act. We are confident that Carbon Engineering's technology will be economic and competitive at commercial scale. We are grateful for the support that the Department of Energy has provided for necessary research and development work. We also acknowledge the support that the 45Q tax credit has provided to help secure investment from the petroleum sector. And we recognize that California's Low Carbon Fuel Standard provides long-term market opportunity by incentivizing the permanent sequestration of carbon dioxide, regardless of location, and the production of low carbon fuels for the transportation sector.

But we hope you will recognize that there are significant challenges to developing the first-of-its-kind version of any new technology, and our technology is no exception. We believe the USE IT Act proposal, to the extent that it increases focus on direct air capture of carbon dioxide, will be an added incentive to potential investors in our sector. There are multiple measures that, as we understand them, will help both carbon capture and storage projects, as well as direct air capture projects. We especially agree that outcome-based investment, such as the "technology prize" mentioned in the USE IT Act proposal, is a viable approach for the Congress to encourage because it requires the government to take less risk, even if ultimate investments would be higher. We would note, however, that Carbon Engineering's critical path to market – now that our technology is demonstrated and that we have industry demand – is to raise financing for a first-of-a-kind commercial scale Direct Air Capture plant, for which a prize may not be the right mechanism. Nonetheless, we support and endorse the “technology prize” described in USE IT, in the context that it will encourage more actors, more research projects, and more focus on the direct air capture space. We would encourage continued discussion with leaders in our field to determine how to provide the right support to anchor development of this new technology in the United States.

I would like to take this opportunity to point out that there is one other way that the federal government could help Carbon Engineering and companies like it to manage the risks associated with bringing new technologies to market. I have mentioned Carbon Engineering’s Air to Fuels technology, which can directly synthesize liquid fuels from captured atmospheric CO_2 and clean electricity. At present time, our feedstock – ambient air – is not among those feedstocks which are approved in the Renewable Fuels Standard to generate RIN credits. It simply was not anticipated when the legislation was written. If fuels generated by the Air to Fuels process were eligible to generate RINs, the economics of the process would be greatly enhanced and would allow us to finance such facilities from competitive capital markets. Increased deployment of Air to Fuels facilities would help parties obligated under the RFS, would create clean burning fuels for American consumers, and would unlock increased business activity in the wind and solar electricity sectors.

Mr. Chairman, again, I appreciate very much the opportunity to discuss Carbon Engineering’s new technologies and how they may be affected by the language of the newly re-proposed USE IT Act. We look forward to continuing to work with you on this and related matters.